Real-time monitoring of patients on remote sites

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Abstract:
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Index Terms:
patient monitoring; telemedicine; biomedical telemetry; computerised monitoring; multimedia commu teleconferencing; information resources; Internet; client-server systems; real-time patient monitoring s site; vital signs monitoring; first-aid treatment advice; monitoring information service; multimedia con service; electrocardiogram; respiration; blood oxygen saturation; invasive blood pressure; noninvasiv pressure; temperature monitoring; alarms generation; real-time multimedia desktop conferencing faci care; Ethernet LAN environment; telemedicine; client-server architecture

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ABSTRACT

In this paper, we present a real-time patient monitoring system, which enables medical doctors to watch their patients on a remote site, to monitor their vital signs and to give them some advice for first-aid treatments. The system consists of three service objects: Monitoring Information Service (MIS), Vital Sign Monitoring Service (VSMS) and Multimedia Consulting Service (MCS). Through the MIS, medical doctors can get information about the patients currently under monitoring, including their names, ages, genders, symptoms, current main complaints and current locations. The VSMS enables medical doctors to monitor in real-time patients' vital signs such as electrocardiogram (ECG), respiration, temperature, blood oxygen saturation (SpO_2), invasive blood pressure (IBP), and non-invasive blood pressure (NIBP). It also generates alarms when the patients are likely to be in a critical situation. The MCS provides a real-time multimedia desktop conferencing facility for watching patients and instructing attendants to administer some first-aid treatment. We carried out some experiments according to two different scenarios. The intensive patient monitoring service was functioning well in a 100Base-T Ethernet LAN environment.

Keywords: Patient Monitoring, Vital Sign Monitoring, Multimedia Consulting Service, Monitoring Information Service, Vital Sign Monitoring Service.

INTRODUCTION

Typically, patient monitoring has been performed to watch, warn, or caution if there is a life-threatening event; physiological parameters such as ECG, blood pressure, body temperature, SpO_2, respiration are measured, processed and interpreted to assess the patient state [1-6]. Presently, patient monitoring systems are mostly installed in ICUs (Intensive Care Units) or CCUs (Coronary Care Units). However, many chronic patients discharged from hospitals, elderly and disabled people at home also often desperately need intensive monitoring. The cost of sending nurses or medical doctors to attend patients at home is very high. To provide a comparably reliable and comfortable but inexpensive way of monitoring for those people using recently available telecommunication technologies, we developed three services: Monitoring Information Service (MIS), Vital Sign Monitoring Service (VSMS) and Multimedia Consulting Service (MCS). Since most people at home can hook up to the Internet through public telephone network due to the recent popularity of the Internet, we put emphasis on the availability over the Internet.

In designing the services for monitoring patients at home through the Internet, we take into account the following functional requirement [1].

(1) Vital signs crucial to assess the patient state, such as ECG, respiration, temperature, SpO_2, invasive blood pressure, and non-invasive blood pressure, should be continuously monitored in real-time.

(2) A life-threatening or intervention-required situation should be identified to generate alarms, which prompt medical doctors to pay attention. Not only the extremely high or low state of heart rate, respiration rate, and blood pressure, but also the malfunction of the instruments such as ECG lead faults should be immediately informed.

(3) Medical doctors and patients should be able to talk face to face with each other.

(4) Medical doctors should be able to browse a list of patients currently being monitored and to obtain fundamental patient information such as their names, ages, genders, main complaints, current locations, etc.

(5) Medical doctors should be able to remotely control monitoring hardware equipment, such as ECG lead selection and the start and stop of noninvasive blood pressure measurement.

SYSTEM CONFIGURATION

Figure 1 shows the overall system configuration. The doctor workstation is just a popular multimedia PC, which is equipped with a microphone, speakers, and a video camera. Any additional hardware device is not required. The patient workstation is also based on a popular multimedia PC with a microphone, speakers, and a video camera, but it has an additional biological signal acquisition unit having various physiological parameter modules. Any Windows NT server machine can be a MIS server if a MIS server program is running on it. The servers and workstations are connected through the Internet. Normally, doctor workstations are located in hospitals, but sometimes they may be installed at doctors' home. In most cases, patient workstations are located at patients' home and are connected to the Internet through an ISDN or a LAN.

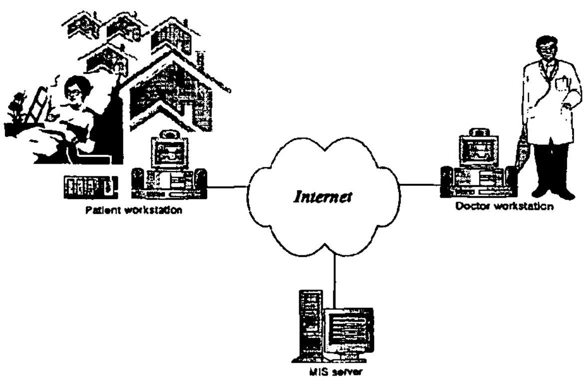

Fig. 1. System configuration.

MONITORING INFORMATION SERVICE (MIS)

The MIS is a service that enables the medical doctor to browse a list of patients currently being monitored and to obtain fundamental information such as their names, ages, genders, main complaints and current locations. The MIS server keeps a list of patients currently under monitoring and it also contains the information about what kinds of services are currently active. On initiating the services such as VSMS and MCS, patient and doctor workstations inform the start of the services to the MIS server. The MIS server contains a database management system (DBMS) that stores the information regarding patients and medical doctors. Hospital registrars can add the patient information to the database. They can also modify, remove and retrieve the contents in the database. Upon getting a query from a client, the MIS server searches, retrieves the requested information from the database and sends it to the client. The client can also register patients or medical doctors to the DBMS.

Before starting consultation, medical doctors usually browse a list of patients to find their patient or a patient who needs a doctor's attention. They then get the IP address of the patient and make a connection to him. Patients also browse a list of medical doctors to find their physician and to know the doctors currently available for consultation on the Internet.

By exchanging User Datagram Protocol (UDP) messages, all the interactions are performed between a MIS server and its clients. The MIS server shows updated information about which medical doctors are currently consulting with which patient.

Eventually, the MIS server will record all the monitoring and consultation history performed on the Internet. It will also record all the advice and instructions given to the patients and a life-threatening events or warnings identified by VSMS server. They are stored with time and date. A MIS server is designed to monitor multiple VSMS and MCS sessions at the same time.

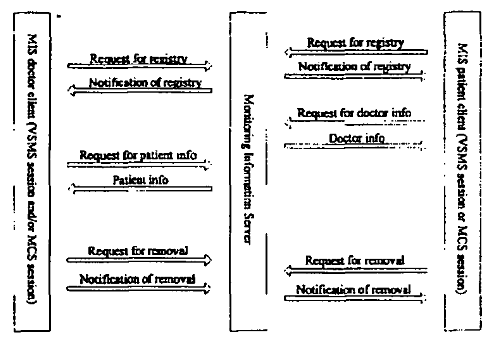

Fig. 2. Message exchange between a MIS server and its clients.

VITAL SIGN MONITORING SERVICE (VSMS)

The VSMS is a service that enables medical doctors to monitor in real-time patients' vital signs such as electrocardiogram (ECG), respiration, temperature, blood oxygen saturation (SpO_2), invasive blood pressure (IBP), and non-invasive blood pressure (NIBP). Presently, patient's critical situations could be identified with integrated monitoring of patient variables: heart rate, respiration rate, blood pressure, oxygen saturation, and temperature. At the critical situation, sound and visible alarms are generated to alert the medical doctors in remote sites. The medical doctors can also change hardware settings such as ECG leads and trigger NIBP measurement, adjust the chart speed and sensitivity of physiological signal graphs, and review the trend of patient physiological variables.

The service is implemented using client/server architecture. The VSMS server is a conventional PC equipped with a real-time biological signal acquisition unit having various physiological parameter modules for amplifying, digitizing, and processing biological signals. The IEEE 485 and HDLC protocols are used for the communication between the PC and the acquisition unit. The VSMS server is a modified version of the component-style

bedside patient monitor wc dcvcloped, which pcrforms the acquisition of biological signals, process them to get patient vital signs and to generate alarms [2-5]. The VSMS server necessarily has a single monitoring session in which biological signals are acquired, processed and transmitted to its clients in real-time through the Internet. We call it a local monitoring session. A VSMS server can manage multiple clients simultaneously. If multiple clients are connected to a single VSMS server, it sends the same biological signal data to its clients one at a time. Normally, the VSMS server is located at a patient bedside.

The VSMS client runs on a conventional PC with a VSMS client program. It shows all the information it receives from the server; draws biological signal data, displays physiological variables, and annunciates alarms. In the VSMS client, there may exist many monitoring sessions. Each session shows all the information including biological signals for a specific patient. We call it a remote monitoring session. Normally, the VSMS client is located on a doctor's desktop and can accommodate many remote-monitoring sessions. In other words, a medical doctor can monitor many patients at the same time.

During the VSMS session, there exist two types of messages: administration messages and data messages. Administration messages are used to inform or control the state of monitoring sessions, while data messages include waveforms, hardware control commands and physiological parameters extracted from the signal. Figure 3 shows a message exchange between a VSMS server and its clients during the vital sign monitoring.

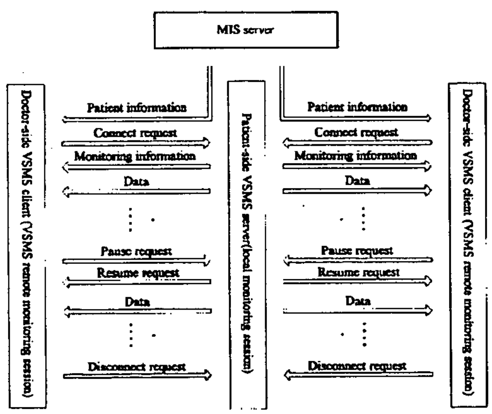

Fig. 3. Message exchange between a VSMS server and its clients.

MULTIMEDIA CONSULTING SERVICE (MCS)

The MCS service provides real-time multimedia desktop conferencing facilities for watching patients and instructing attendants to administer some first-aid treatment. Two medical doctors can confer together about patient's current situation with simultaneously watching the same patient vital signs.

Like other services, the service is also implemented using client/server architecture. The server captures the image and sound from the camera and microphone, and sends them to its client. On reception, the client just plays them. A MCS server corresponds with a single MCS client, and there can exist a MCS server and a MCS client on each PC. To provide MCS, the PC needs to have a H.261 video compression board and a G.711 audio CODEC board. The message exchange between a MCS server and its client is similar to the one in the VSMS.

SYSTEM IMPLEMENTATION

We have developed the above three services under a Windows NT 4.0 environment. Each service is implemented as an independent component, which follows Microsoft's Component Object Model (COM). We defined a common application programming interface, which is called PMAPI (Patient Monitoring API). All the service components implement the common PMAPI interface. There is a main program that dynamically links various service components in run-time environment. It assumes that the service components implement PMAPI interface. The MIS, VSMS, MCS components are written in C++ language and Win32 API [7]. After analyzing the system, we designed and coded many C++ classes. We used the Rational Rose that is an object-oriented analysis and design tool [9]. The MIS and VSMS clients are also implemented as ActiveX controls that can be inserted into Web pages [8]. Data communication through the Internet is implemented using WinSock API. Since each service is implemented as a separate component having common PMAPI interface, the system is modular, extensible, and easily customizable. We used commercialized H.261 compression and G.711 audio CODEC boards.

RESULTS AND DISCUSSION

We built 2 patient workstations, 2 doctor workstations and a MIS server. The demo system configured for test includes all of the workstations, the MIS server, an additional web server and a web client. The web server not only provides the documents about how to use the services, but also provides a starting point of the services. It contains the IP addresses of MIS servers. The patient workstations are with a biological signal acquisition unit, microphone, speakers and a video camera, and the doctor workstations with microphone, speakers and a video camera. The web server runs an Internet Information Server (IIS) on a Windows NT environment. The Microsoft Internet Explorer 4.0 is used as a web browser in the web client. We used a 100 Mbps fast Ethernet switch to connect all of these machines. The configuration is shown in figure 4.

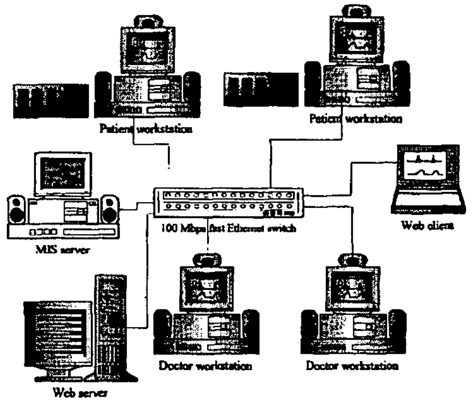

Fig. 4. Demo system.

Figure 5 shows MIS server. It displays a list of patients and doctors, each entry of which contains a name, an ID, service status, an IP address, an age, an address, a phone number, etc. This information is retrieved from the database of the MIS, using the ID its client sent. The entries can be added, modified or removed in the MIS server.

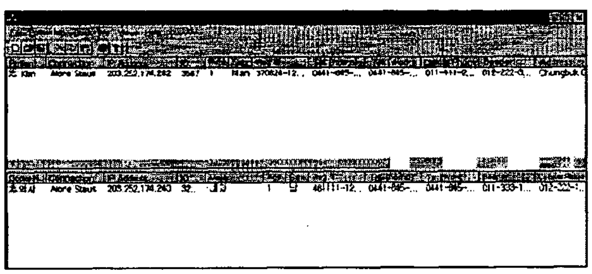

Fig. 5. MIS server.

MIS clients (patient workstations or doctor workstations) or web clients running Microsoft Internet Explorer can get the monitoring information from the MIS server through the Internet. A medical doctor can start consulting or monitoring for a specific patient by selecting a patient and the services of his interest. Figure 6 shows the monitor screen of the doctor workstation running the VSMS and MCS clients. In fact, the corresponding patient workstation has the appearance similar to the doctor workstation.

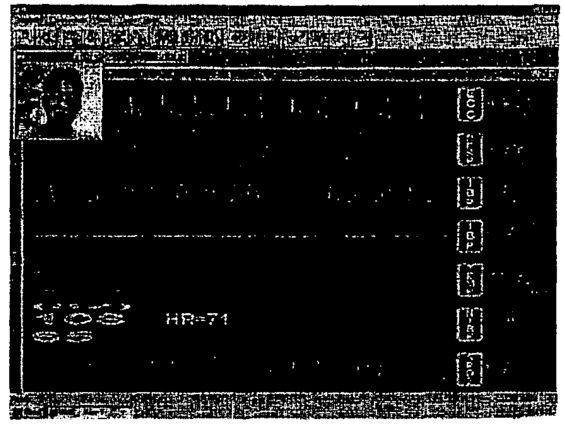

Fig. 6. Doctor workstation

Through the above overlay window, the medical doctor can watch his patient in a remote site (the overlay window is the MCS client window). Although there is no window for audio, he can also talk to his patient. On the VSMS client window, there are ECG, respiration, IBP and SpO_2 waveforms. The current body temperature value and its trend are shown at the TEMP bar and systolic, diastolic pressure values and their average at the NIBP bar.

For each channel, there is a button between the waveform display region and the numeric display region. A mouse click on the button brings up an option dialog box for signal input, data acquisition, signal processing, and waveform display of the corresponding channel. When the options for signal acquisition or signal processing are changed, the change is immediately informed to the patient workstation, which will carry into effect the change. Figure 7 shows an option dialog box for ECG channels.

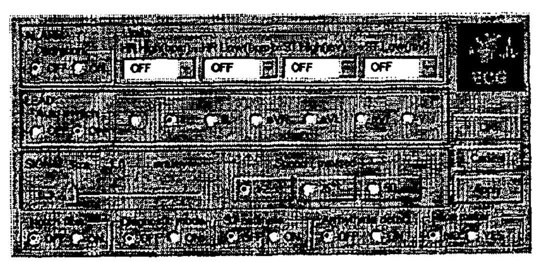

Fig. 7. Option dialog box for ECG channels

We tested the above system according to two different scenarios. First, we made two monitoring sessions, each of which correlated a pair of a doctor and a patient. In the experiment, one medical doctor monitored one patient, while the other medical doctor consulted with the other patient. There was no problem in observing biological signals with simultaneously capturing and displaying about 15 frames of

images. There was no delay when we remotely changed data acquisition hardware settings. Figure 8 shows the configuration.

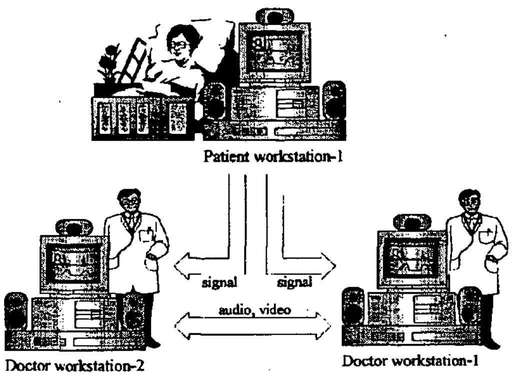

Fig. 8. Scenario-1 configuration

In the second scenario, we started a single VSMS server session for a patient and one MCS session between two medical doctors. In other words, two medical doctors located at two different sites were monitoring a patient's vital signs with talking face to face together. Each doctor's workstation acts as a VSMS client, a MCS server, and a MCS client, while the patient workstation acts only as a VSMS server. In this case, there was no difficulty in observing biological signals with capturing and displaying about 15 frames of images, too. There was no delay when we remotely changed data acquisition hardware settings. Figure 9 shows the configuration.

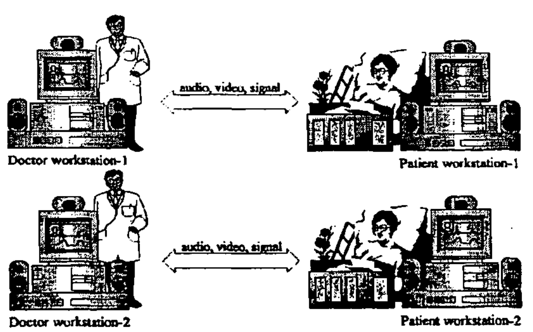

Fig. 9. Scenario-2 configuration

We did not involve many workstations because of the lack of hardware devices. However, It was evident that the 100Base-T Ethernet could deliver high performance enough to accommodate a reasonable number of the intensive patient monitoring sessions. In a near future, we plan to test the system on an ISDN and an ATM network.

CONCLUSIONS

The intensive patient monitoring service we described here enables medical doctors to watch their patients in a remote site, to monitor their vital signs in real-time and to give them some advice for first-aid treatments through the Internet. Through the experiments, we showed that three different services required for intensive patient monitoring were functioning well in a 100Base-T Ethernet network environment. Currently, the system is under clinical test in the Kon-Kuk university hospital. In order to use this system in a PSTN environment, more powerful hardware devices for audio and video compression should be employed.

Presently, we are expanding the MIS database to store biological signals, alarms generated during monitoring, doctor's reports and instructions. We are also converting the service components into ActiveX components.

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